Schroeder

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF SHADEHILL DAM OUTLET WORKS MODIFICATION

Hydraulic Laboratory Report No. Hyd-453

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

September 16, 1959

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Commissioner's Office--Denver	Laboratory Report No. Hyd-453
Division of Engineering Laboratories	Prepared by: G. L. Beichley
Hydraulic Laboratory Branch	Edited by: A. J. Peterka
Denver, Colorado	Reviewed by: J. W. Ball
September 14, 1959	Submitted by: H. M. Martin

Subject: Hydraulic model studies of Shadehill Dam outlet works modification

SUMMARY

The Shadehill Dam outlet works and stilling basin were built at the time the dam was constructed but have not been used. The outlet works was designed to discharge 285 cfs into a canal to be constructed at a future date. Under present modification plans, the capacity of the outlet works will be increased to 600 cfs to provide some reservoir control and the flow will be discharged into the service spillway stilling basin and then into the river until construction of the canal. Hydraulic tests were made on a 1:12.52 scale model to develop the hydraulic design of the proposed outlet works modification.

In the preliminary design of the modification, the existing stilling basin was extended, and a wave suppressor was placed downstream; a spillway crest, transition and 6-foot-diameter pipe were utilized to conduct the flow from the outlet works basin into the existing service spillway stilling basin, from which the flow entered a discharge channel that carried the flow to the river downstream.

Tests on the preliminary design showed the overall arrangement and dimensions of the structure to be satisfactory, but that the hydraulic performance could be improved by the addition or modification of several features.

The addition of a chute block in the existing upstream portion of the basin and three baffle piers in the new downstream portion improved the performance of both the basin and wave suppressor. An overhang of 12 inches was placed on top of the basin walls to contain high waves within the basin. A small deflector followed by a 12-inch air vent was installed in the crown of the transition from

the crest section to the 6-foot pipe. The deflector acted as a constriction and provided a positive control to prevent filling and siphonic action in the pipe if the flow ever exceeded the design discharge. To improve the performance of the service spillway stilling basin for outlet works flows from the 6-foot-diameter pipe that entered the side of the basin, the straight end of the pipe was replaced with a specially shaped piece which curved downward and to the left. Flow passing through the curved piece was thus given a swirling motion and produced a hollow-jet flow pattern as it entered the service spillway basin. The flow entering the discharge channel from the basin was well distributed across the entire width and produced no unusual flow or scour problems.

ACKNOWLEDGMENT

The final plans evolved from this study were developed through the cooperation of the staffs of the Spillway and Outlet Works Section and the Hydraulic Laboratory during the period from January 1959 to March 1959.

INTRODUCTION

Shadehill Dam is part of the Missouri River Basin Project and is located on the Grand River near Lemmon, South Dakota, at the northern border of the state, Figure 1. The reservoir is used for flood control and storage of irrigation water. The dam, Figure 2, is a compacted earthfill structure covered with a protective layer of rock riprap. It's crest is at elevation 2318, 125 feet above the stream bed.

The dam contains an emergency spillway, a service or tunnel spillway, and an outlet works all located in the left abutment. The outlet works, Figure 3, was originally designed to discharge 285 cfs into a stilling basin at the upstream end of a canal. By means of the outlet works modification, Figures 4, 5, and 6, 600 cfs can be discharged from the outlet works stilling basin into the service spillway stilling basin.

The modification includes an extension of the original stilling basin, a wave suppressor and a 6-foot-diameter pipe that discharges outlet works flows into the service spillway stilling basin. Flow enters the pipe after passing over a crest in the transition section located at the downstream end of the outlet works stilling basin extension.

THE MODEL

The model, Figures 7 and 8, was a 1:12.52 scale reproduction of the outlet works modification, including: the outlet works structures, a portion of the service spillway stilling basin, and a short length of discharge channel extending downstream from the spillway stilling basin. The model, constructed as a mirror image of the prototype structure to make use of available laboratory space, was tested in the Bureau of Reclamation Hydraulic Laboratory in Denver, Colorado.

THE INVESTIGATION

The primary purpose of the investigation was to develop the hydraulic design of the outlet works modification for a discharge of 600 cfs. To accomplish this, it was necessary to investigate the hydraulic performance of the outlet works stilling basin, the proposed wave suppressor, the crest in the pipe entrance transition and the transition section, the 6-foot-diameter pipe, and the service spillway stilling basin.

Preliminary Design

The preliminary design of the modification as tested is shown in Figure 9. Initial investigation showed the general concept of the preliminary design to be satisfactory but that several features needed improvement.

The design flow of 600 cfs entering the outlet works stilling basin will have a Froude number between 2.5 and 3.5, depending upon the roughness of the conduit between the reservoir and the outlet portal. For a roughness coefficient in Mannings equation of $n = 0.013$, the Froude number is 2.5, and the velocity of the flow at the portal is 26.1 feet per second. For $n = 0.008$ the Froude number is 3.5, and the velocity is 31.35 feet per second. Since the roughness of the prototype is not known, tests were made for these n values. Both flow conditions in the basin are shown in Figure 10. The water surface was extremely unstable and was accompanied by severe wave action downstream, particularly for the higher Froude number. For the high Froude number, the toe of the jump moved 20 feet upstream and downstream in the basin, and waves splashed over the training wall. The wave action was dampened considerably by the wave suppressor; however, surging persisted on the downstream side of the suppressor. The suppressor was relatively ineffective because the jump formed so close to the suppressor that turbulent flow persisted through the deflector and caused a boil along the training wall at the downstream end of basin extension. This boil caused unsymmetrical flow over the crest and at the entrance to the 6-foot-diameter pipe. Thus, because the flow was unsymmetrical it had a tendency to zigzag through the pipe. This action was not severe, however, and flow through the pipe was considered to be satisfactory.

At the outlet portal of the 6-foot-diameter pipe, the flow plunged into the service spillway stilling basin pool, striking near the opposite wall, and causing a large boil along the wall as shown in Figure 11A. The concentrated flow caused considerable erosion in the movable sand bed of the discharge channel, Figure 11B. At the downstream corner of the basin the sand bed was eroded to the floor of the model box which was at prototype elevation 2182. Sand from the other side of the discharge channel was carried into the basin and deposited to elevation 2186.5.

Recommended Design

The recommended design, shown in Figures 4, 5, and 6, resulted from tests made on several intermediate designs in which various arrangements of baffle piers, sills, and other appurtenances were evaluated in terms of hydraulic performance.

Outlet Works Basin. For the recommended basin 1 streamlined chute block, 3 feet 9 inches high by 2 feet 6 inches wide, was installed at the upstream end of the existing outlet works stilling basin; and 3 piers 20 inches wide by 7 feet high, tied together by means of a slab across their tops, were installed at the upstream end of the stilling basin extension, Figure 12. In addition, a 12-inch overhang was placed on the tops of the basin training walls to contain the high waves within the basin.

The chute block and baffle piers were necessary because the depth in the basin was not sufficient to develop and hold the hydraulic jump in the upstream or original portion of the basin. The 1 large chute block proved to be more effective than 2 or 3 smaller ones. The use of 1 block would simplify prototype construction since adding only 1 chute block to the existing prototype structure was considered to be less difficult than constructing 2 or 3 smaller ones. The model tests had indicated that 3 equally spaced piers 1 foot wide by 1.5 feet high, or 2 piers 1.5 feet wide by 2 feet high placed about 15 to 20 feet downstream from the chute block would improve the hydraulic jump and provide more uniform flow beneath the wave suppressor. In this location extensive alterations to the existing structure would be required. Therefore, it was decided to place larger baffles farther downstream at the beginning of the new construction, Figures 4 and 12. These recommended baffle piers improved the stilling action of the hydraulic jump and wave suppressor almost as much as the smaller piers in the upstream position. The improvement over the preliminary design can be seen by comparing Figures 10 and 13. The water surface was smoother and the flow was more stable both upstream and downstream from the wave suppressor over a wide range of outlet works flows for both values of entrance flow velocities.

It was determined that the poor flow condition at the entrance to the pipe could be alleviated by placing a guide wall between the wave suppressor and the pipe entrance, as shown in Figure 13. In effect, this wall provided a streamlined approach to the pipe entrance which helped to uniformly distribute the flow over the crest. A 15-inch-high sill on the basin floor, used in place of the guide wall, and located 3 or 4 feet farther upstream served the same purpose but was not quite so effective. However, the improvement afforded by these means was not deemed necessary, considering the added cost, and the wall or sill were not adopted or recommended for prototype construction.

The outlet works was found to be capable of discharging flows up to 750 cfs if emergency conditions ever made this necessary, Figure 14. Flows of 800 cfs spilled over the outlet works basin training walls. The basin also performed well in discharging less than design flow, Figure 14. For the original outlet works design flow of 285 cfs at low velocity, the jump formed within the tunnel below the control gate, filling the tunnel to the crown at the portal. Increasing the velocity to provide a Froude number of about 3.5 caused the jump to move downstream into the basin. Neither flow condition seemed to be objectionable since the tunnel is vented upstream at the radial control gate.

Pipe Entrance. A small deflector followed by a 12-inch air vent was installed in the crown of the transition section downstream from the crest section, Figures 4, 12, and 15. The purpose was to provide a positive control to prevent filling and siphonic action in the 6-foot-diameter pipe downstream if the design flow was ever exceeded. For flows up to 800 cfs, the pipe did not fill, Figure 15. For flows of 800 cfs some water spilled over the outlet works wall upstream from the wave suppressor. This action would be visible to the operators of the prototype structure and would indicate that the capacity of the structure had been exceeded. Pressures were recorded at piezometers in the crest section and entrance portal transition section, Figures 12 and 16. No subatmospheric pressures were detected.

The crest was calibrated, Figure 17, using the staff gage on the right-hand wall downstream from the wave suppressor as the head-measuring station, Figure 4. The capacity of the crest section was satisfactory. For the higher discharges the water surface at the gage fluctuated as shown. For 600 cfs the average fluctuation was about 10 inches and sometimes more.

Pipe Exit. To improve the performance of the service spillway stilling basin in dissipating the energy in outlet works discharges, the straight end of the 6-foot-diameter pipe was replaced with a curved trajectory piece, Figures 5, 6, and 12. The center line of the trajectory curved downward 27° from the center line of pipe on about a 45-foot radius and was rotated clockwise 45° from the downward position. The end piece was made from 5 pieces of straight pipe cut and assembled as shown in Figure 5. Flow entering the end piece had sufficient velocity to spin over the crown of the pipe and form a hollow jet almost annular in shape. Flow emerging from the end had a swirling motion which caused the diameter of the jet to expand, Figure 18. The spinning jet was readily broken up as it entered the tail water and spread laterally across the stilling basin width. The flow passed through the stilling basin pool in such a way that a minimum amount of disturbance resulted. Only minor erosion of the river bed occurred, Figure 18, and since this area is protected by riprap in the prototype structure, no erosion problems are expected to occur. Other degrees of end piece curvature and other degrees of rotation both to the left and to the right were tested, but were not as effective as the recommended design.

FIGURE 1
REPORT HYD.-453

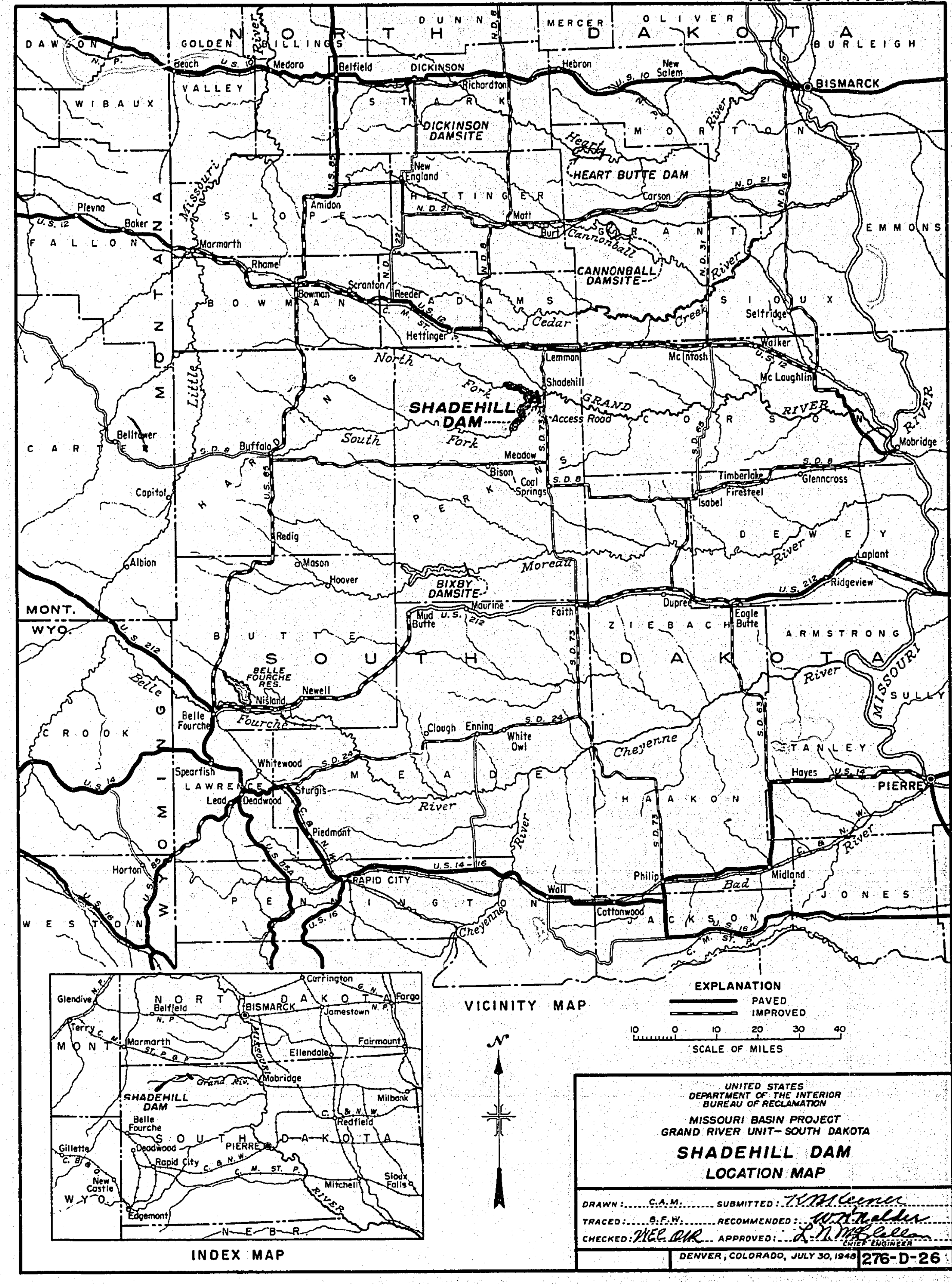
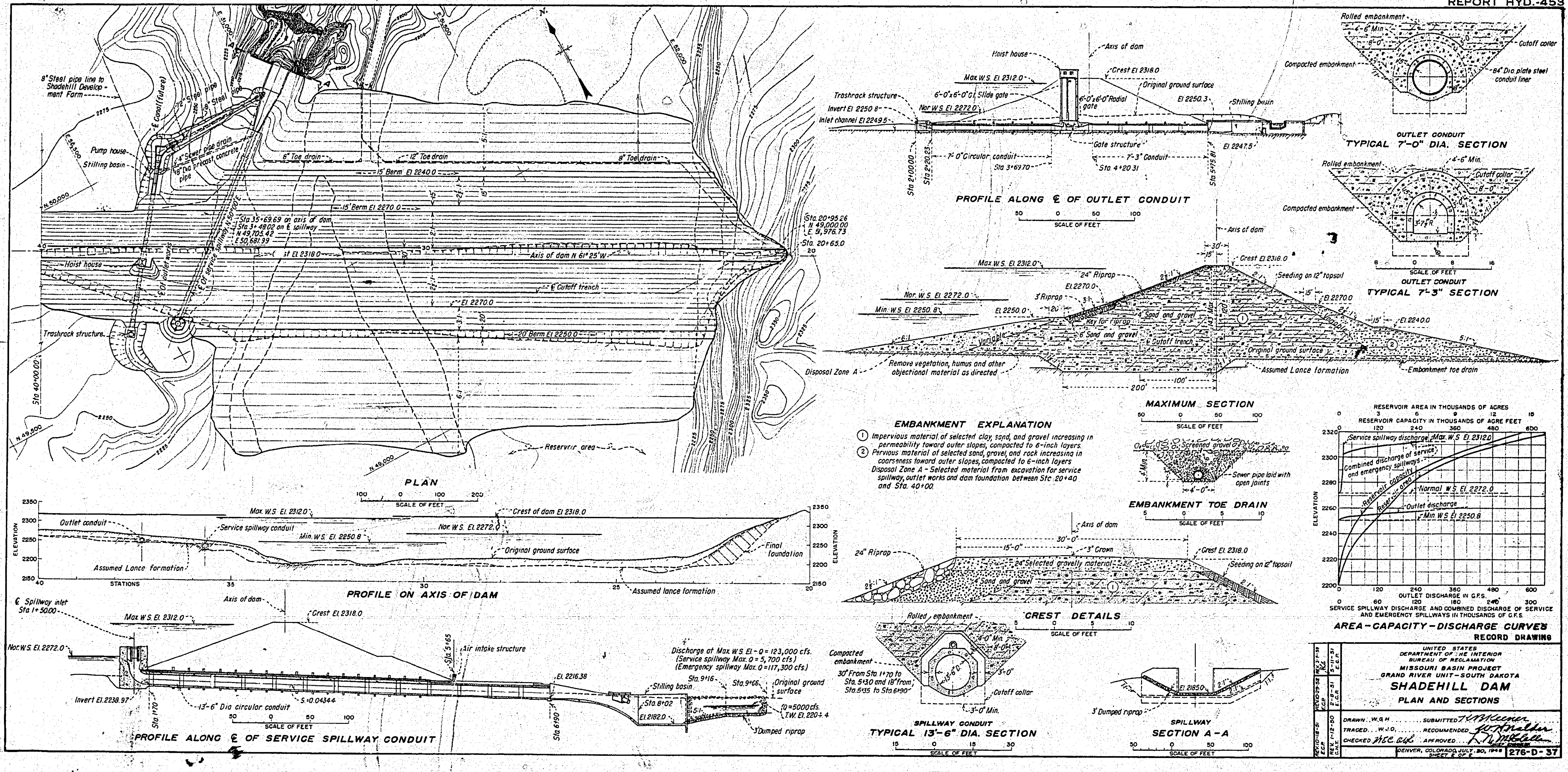


FIGURE 2
REPORT HYD.-453



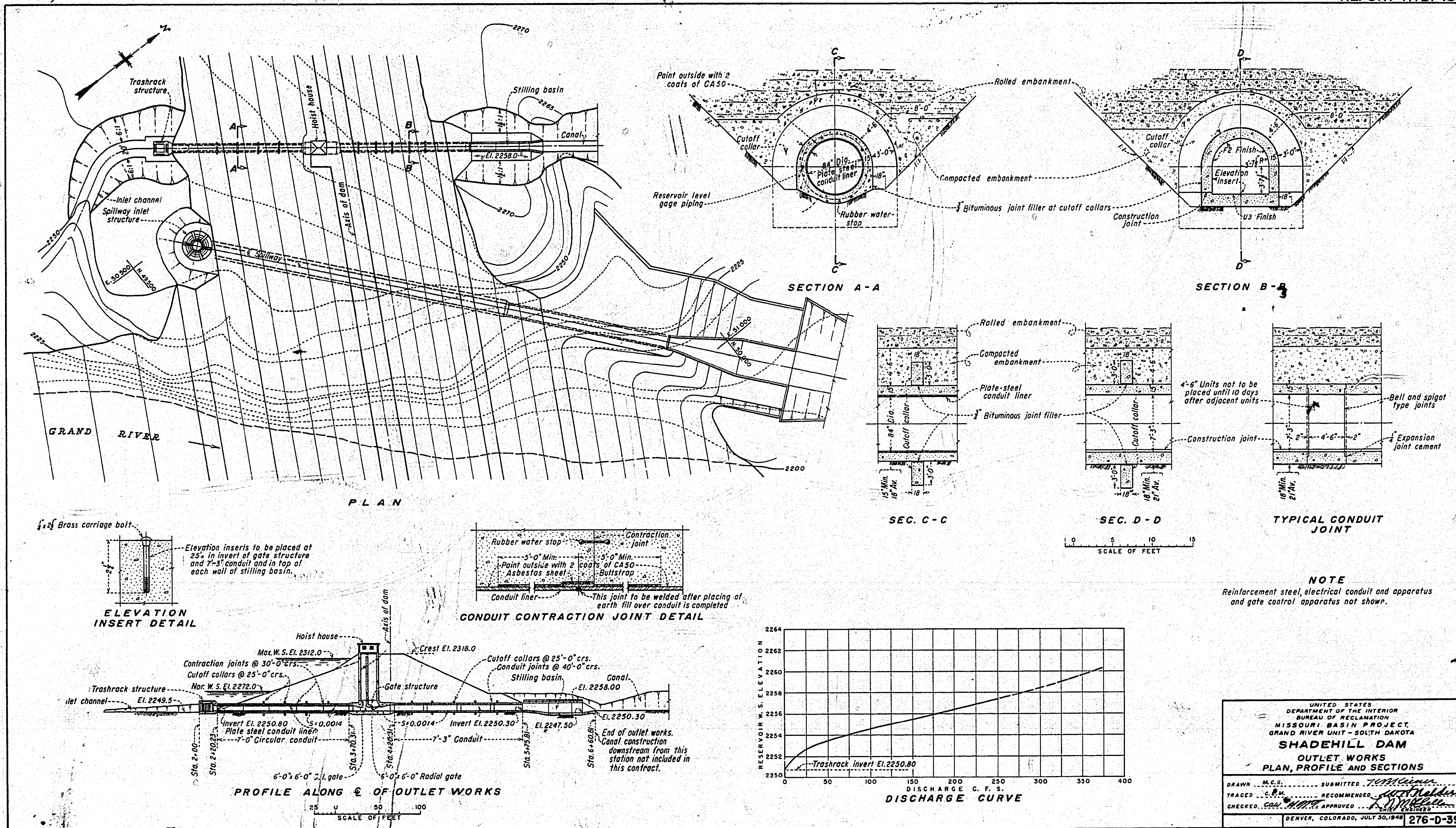
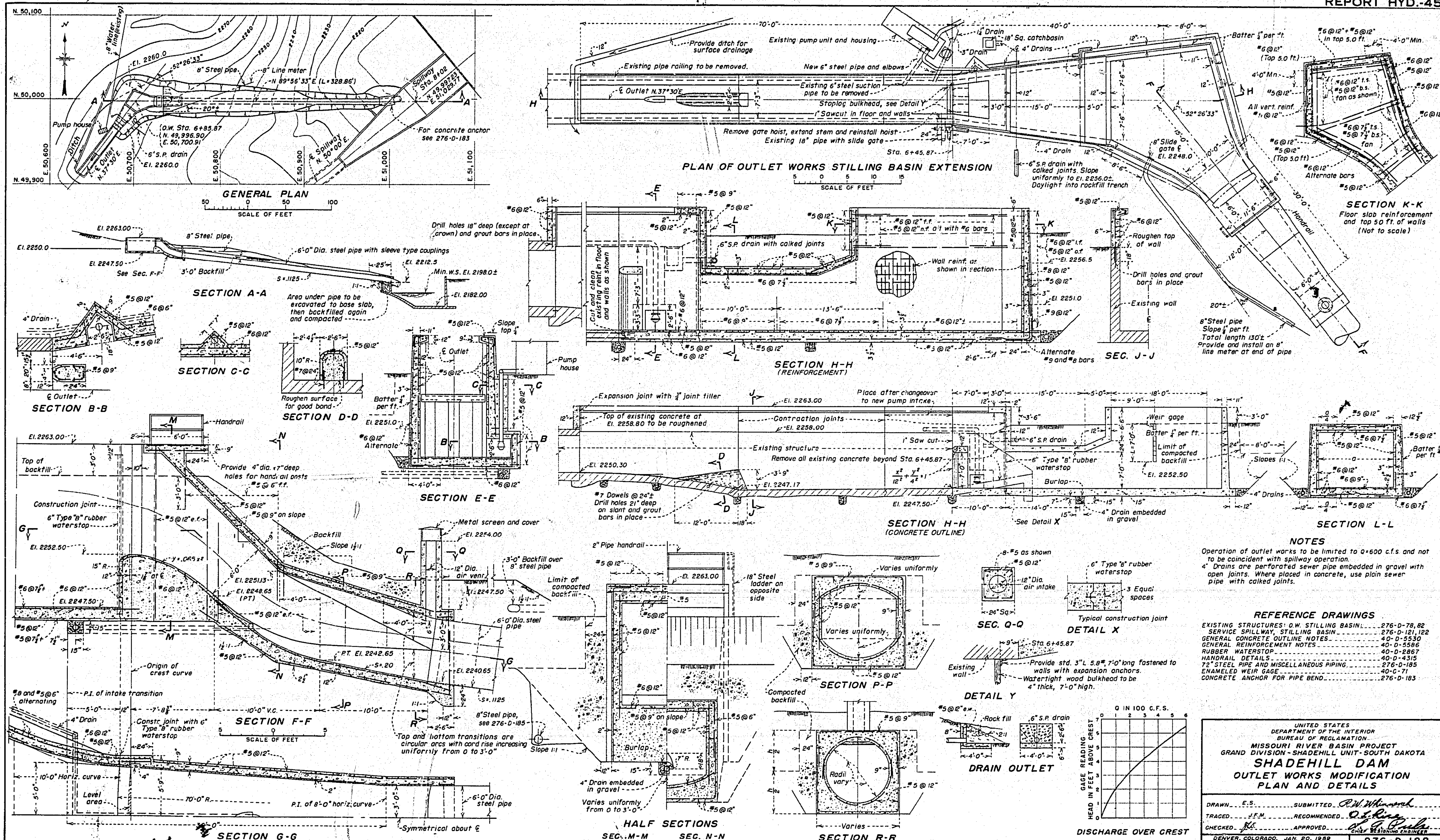
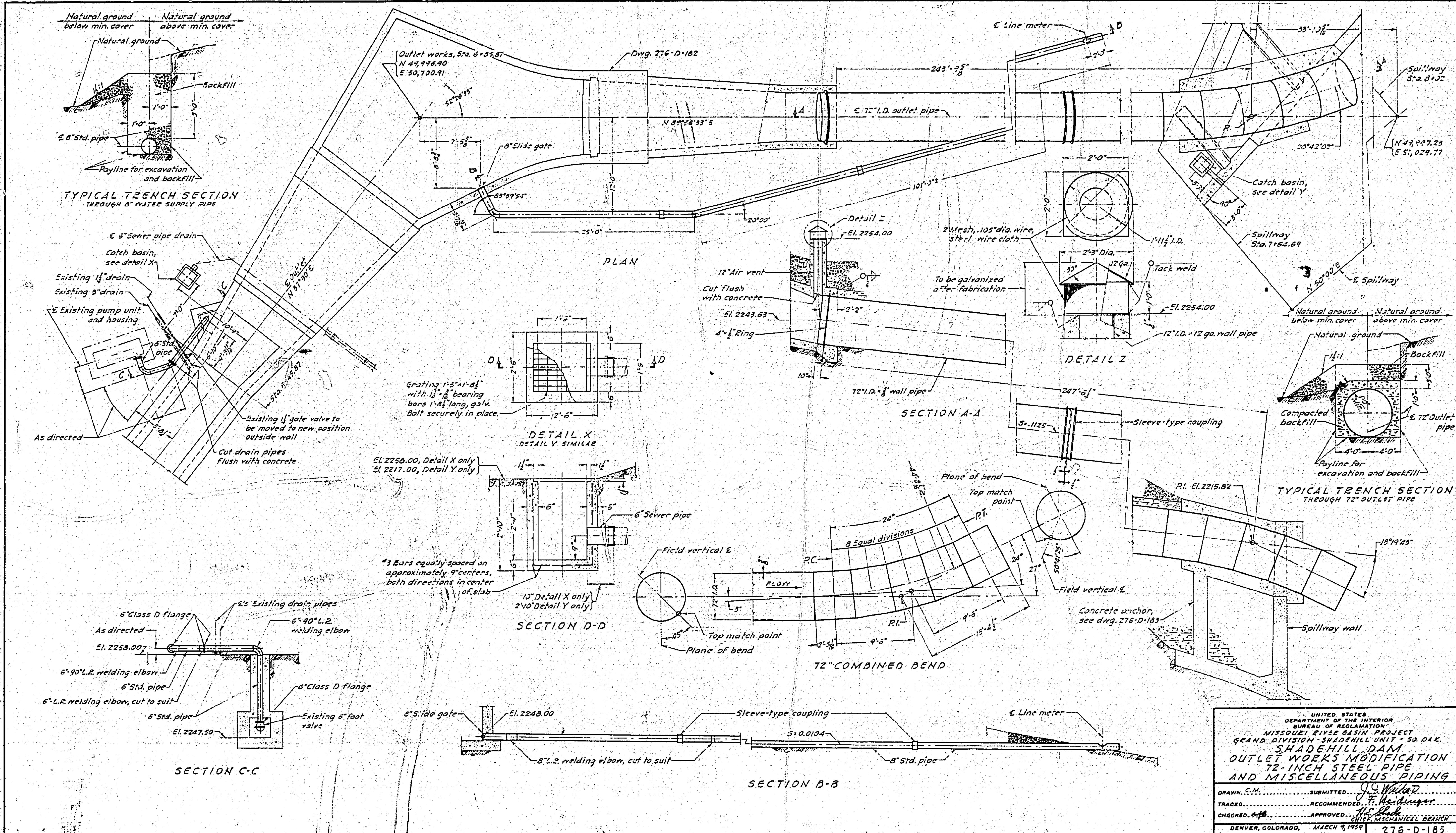

PLAN
Trashrack structure
Hoist house
Stilling basin
Canal
El. 2258.0
Axis of dam
Inlet channel
Spillway inlet structure
℄ Spillway
E. 50,500
N. 49,500
E. 51,000
N. 50,000
GRAND RIVER
SECTION A-A
Paint outside with 2 coats of CA50
Rolled embankment
Cutoff collar
84" Dia. Plate steel conduit liner
Compacted embankment
Reservoir level gage piping
Rubber water-stop
3/4" Bituminous joint filler at cutoff collars
SECTION B-B
F2 Finish
Elevation insert
Construction joint
U3 Finish
SEC. C-C
SEC. D-D
TYPICAL CONDUIT JOINT
Plate-steel conduit liner
3/4" Bituminous joint filler
4'-6" Units not to be placed until 10 days after adjacent units
Construction joint
Bell and spigot type joints
1/4" Expansion joint cement
SCALE OF FEET
NOTE
Reinforcement steel, electrical conduit and apparatus and gate control apparatus not shown.
1/2"x2 1/2" Brass carriage bolt
Elevation inserts to be placed at 25'± in invert of gate structure and 7'-3" conduit and in top of each wall of stilling basin.
ELEVATION INSERT DETAIL
Rubber water stop
Contraction joint
5'-0" Min.
Paint outside with 2 coats of CA50
Asbestos sheet
Buttstrap
Conduit liner
This joint to be welded after placing of earth fill over conduit is completed
CONDUIT CONTRACTION JOINT DETAIL
Hoist house
Axis of dam
Max. W. S. El. 2312.0
Crest El. 2318.0
Contraction joints @ 30'-0" crs.
Cutoff collars @ 25'-0" crs.
Cutoff collars @ 25'-0" crs.
Conduit joints @ 40'-0" crs.
Nor. W. S. El. 2272.0
Stilling basin
El. 2258.00
Canal
Trashrack structure
Inlet channel
El. 2249.5
Gate structure
Invert El. 2250.80
S=0.0014
S=0.0014
Invert El. 2250.30
El. 2247.50
El. 2250.30
Plate steel conduit liner
7'-0" Circular conduit
7'-3" Conduit
End of outlet works. Canal construction downstream from this station not included in this contract.
Sta. 2+00
Sta. 2+20.25
Sta. 3+70.31
Sta. 4+20.31
Sta. 5+75.81
Sta. 6+60.81
6'-0"x6'-0" J.I. gate
6'-0"x6'-0" Radial gate
PROFILE ALONG ℄ OF OUTLET WORKS
RESERVOIR W. S. ELEVATION
Trashrack invert El. 2250.80
DISCHARGE C. F. S.
DISCHARGE CURVE
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
GRAND RIVER UNIT - SOUTH DAKOTA
SHADEHILL DAM
OUTLET WORKS
PLAN, PROFILE AND SECTIONS
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHIEF ENGINEER
DENVER, COLORADO, JULY 30, 1946
276-D-39

FIGURE 4
REPORT HYD.-453

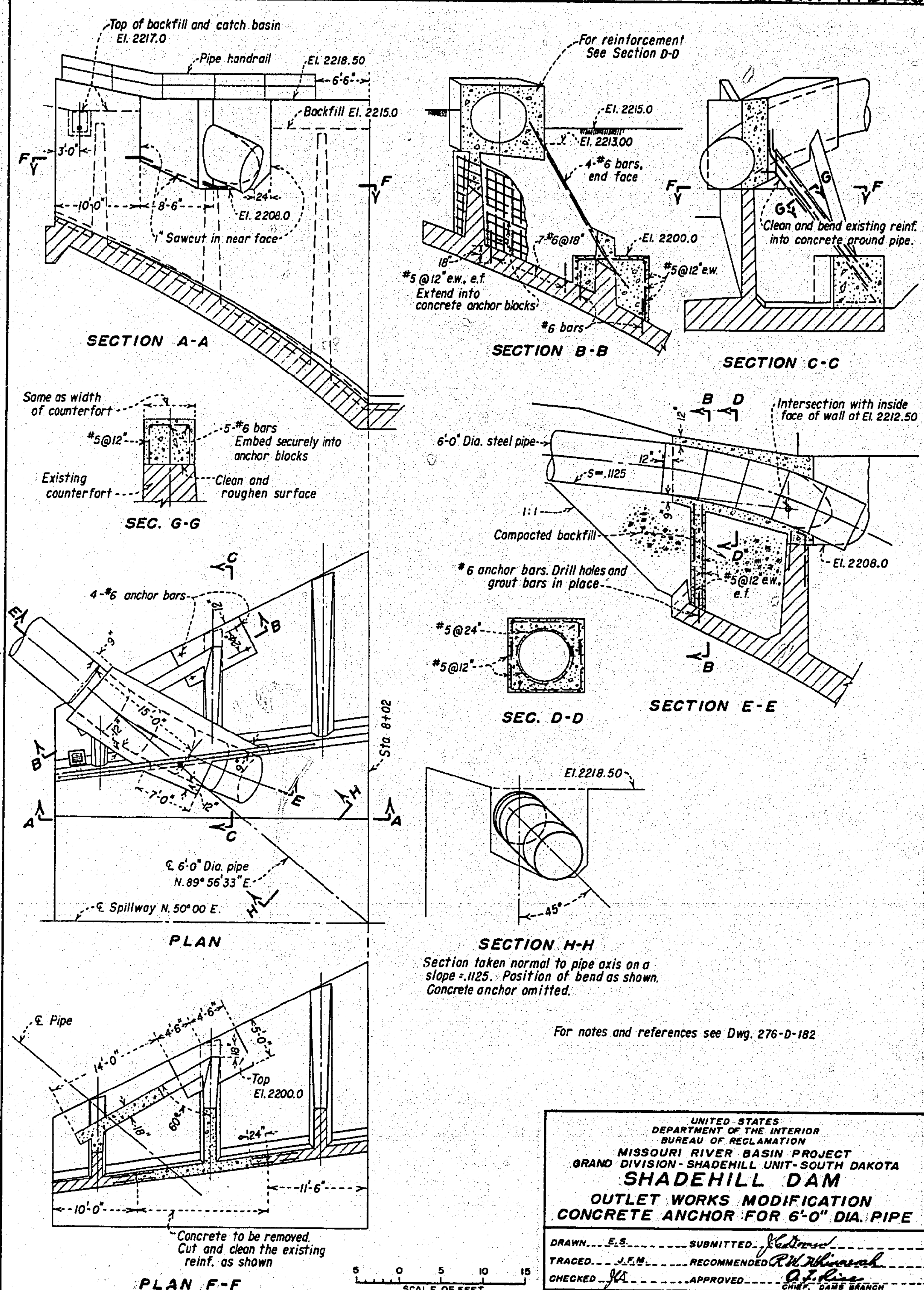




UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
GRAND DIVISION - SHADEHILL UNIT - SO. DAK.

SHADEHILL DAM
OUTLET WORKS MODIFICATION
72-INCH STEEL PIPE
AND MISCELLANEOUS PIPING

DRAWN C.M.	SUBMITTED J.C. Waite		
TRACED	RECOMMENDED J.F. Heidinger		
CHECKED	APPROVED H.E. Buck, CHIEF, MECHANICAL BRANCH		
DENVER, COLORADO,	MARCH 9, 1959	276-D-185	

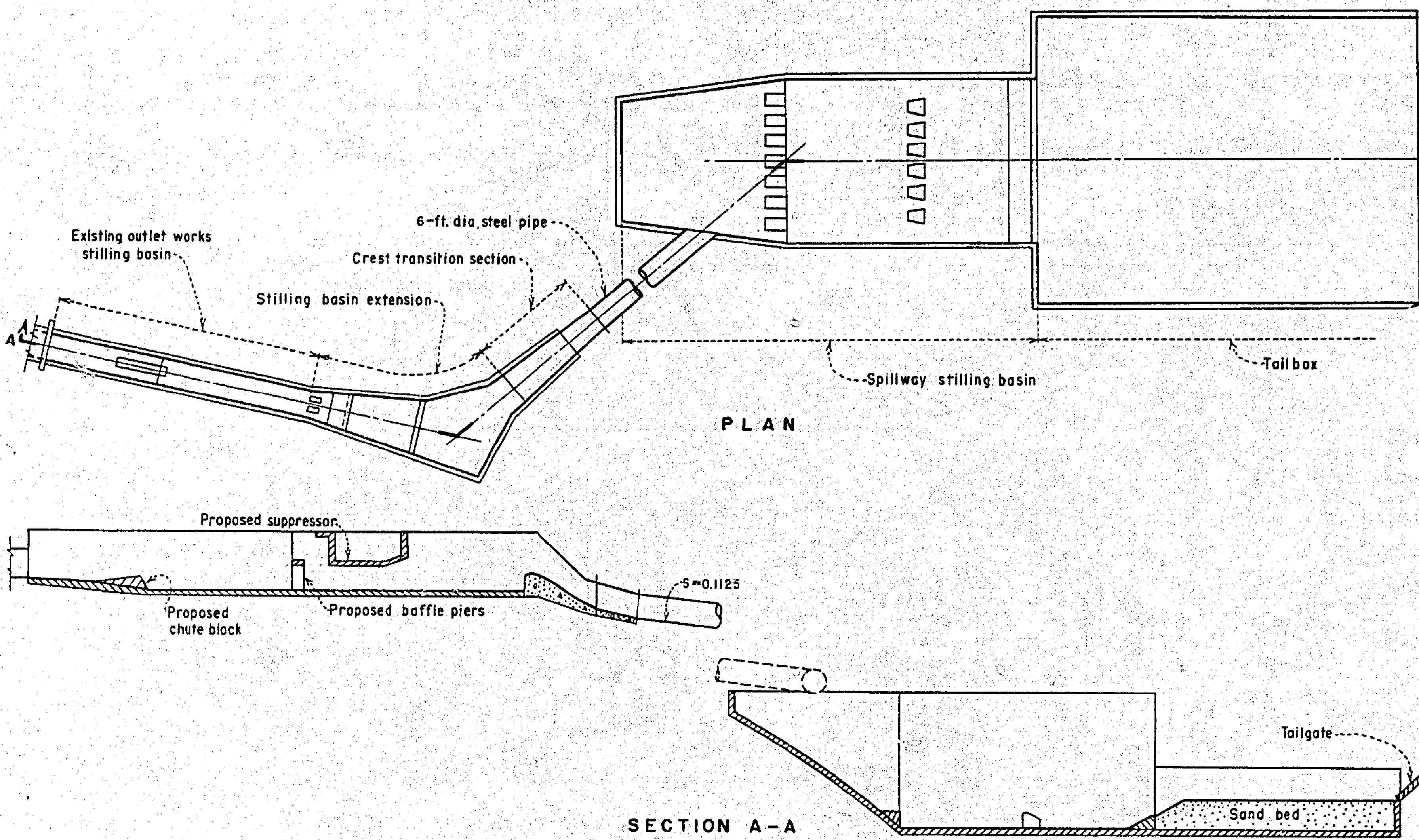


UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
GRAND DIVISION - SHADEHILL UNIT - SOUTH DAKOTA

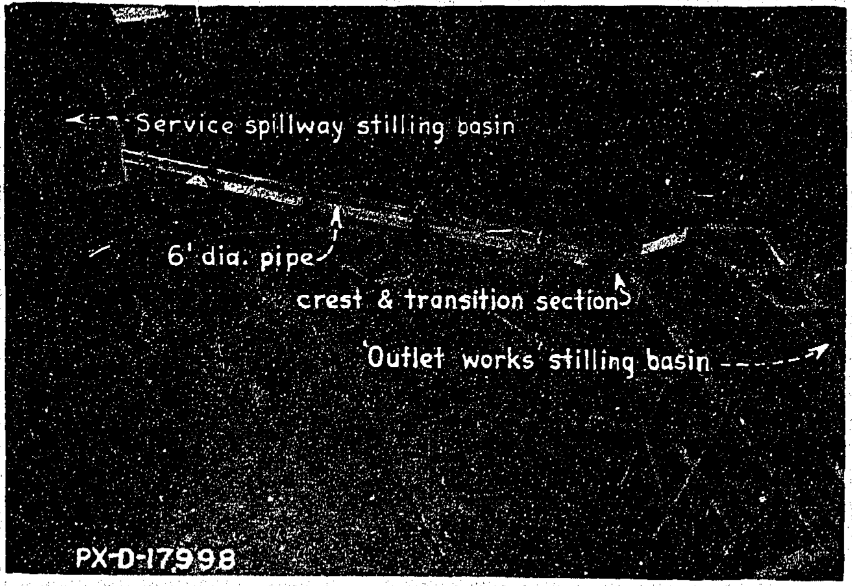
SHADEHILL DAM

OUTLET WORKS MODIFICATION
CONCRETE ANCHOR FOR 6'-0" DIA. PIPE

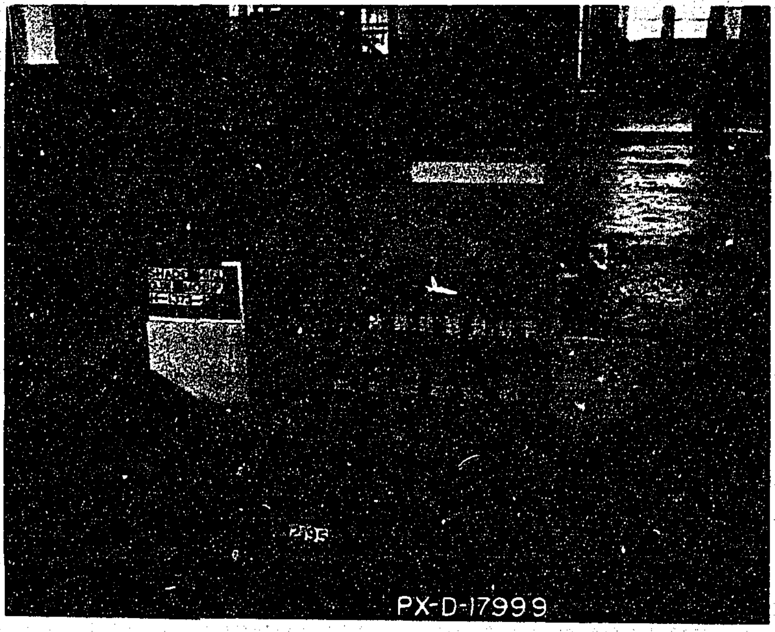
DRAWN E.S. SUBMITTED J.C. Dorson
TRACED J.F.M. RECOMMENDED R.W. Klinesak
CHECKED J.K.S. APPROVED O.F. Rice, CHIEF, DAMS BRANCH
DENVER, COLORADO, MARCH 5, 1959 — 276-D-183



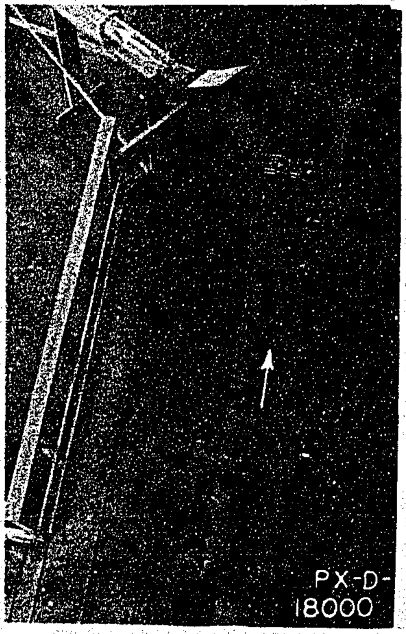
SHADEHILL DAM OUTLET WORKS
MODEL LAYOUT
1:12.52 SCALE MODEL



A. Overall view of model



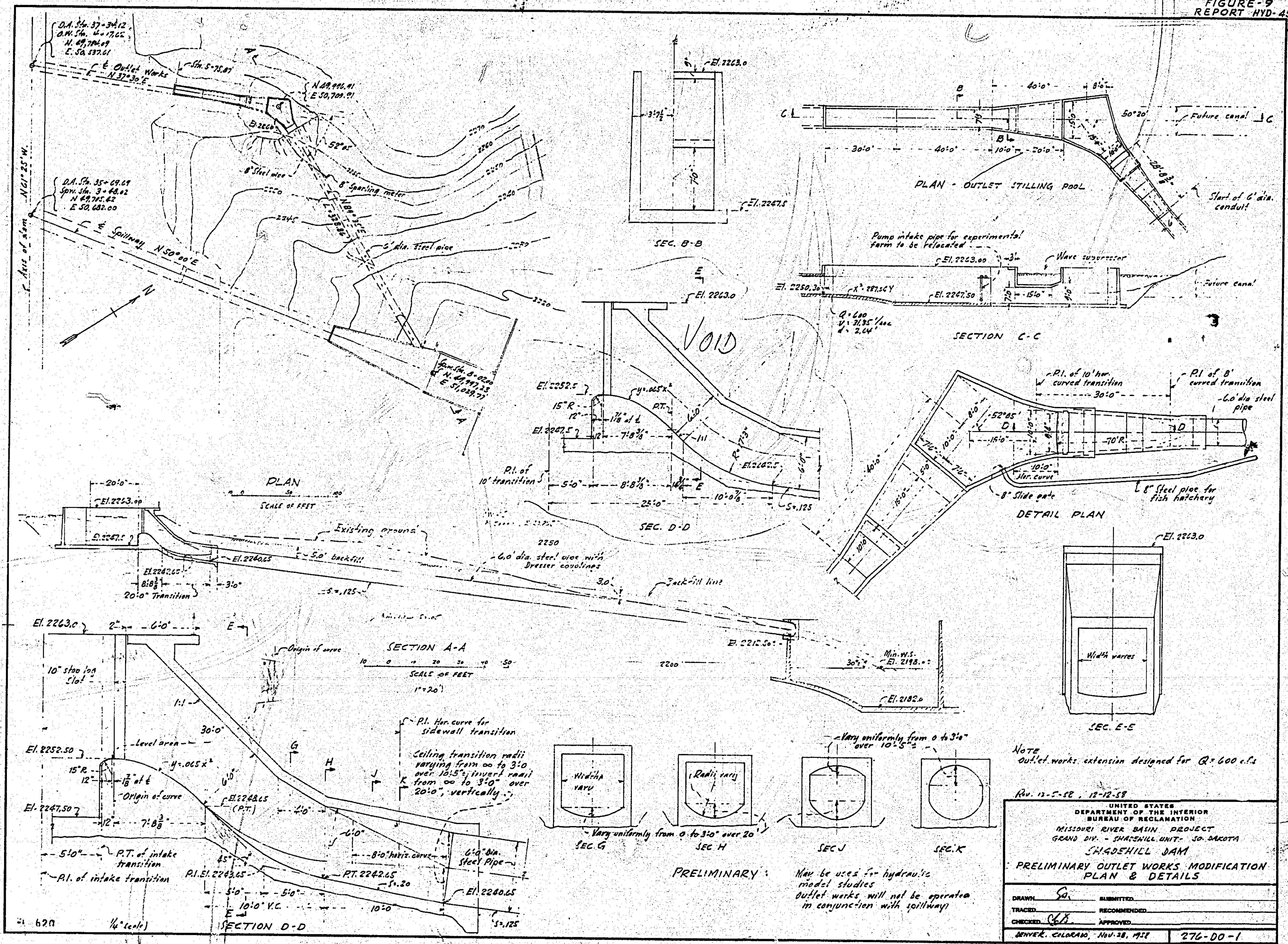
B. Service spillway stilling basin

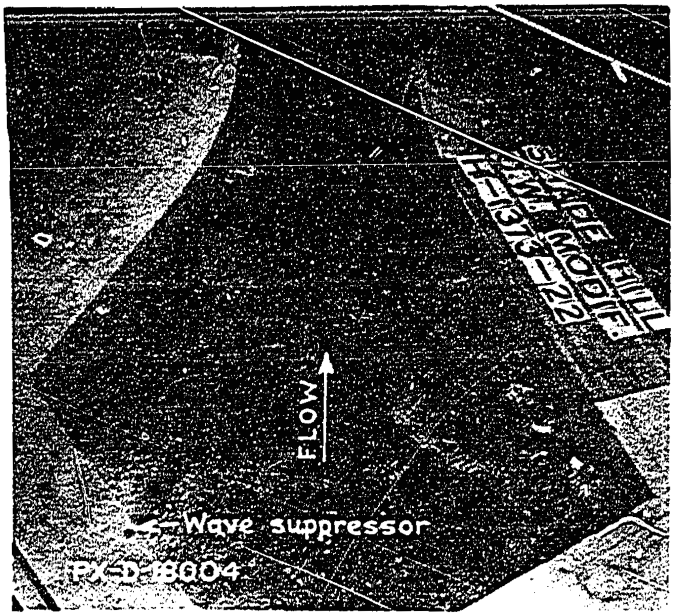


C. Outlet works stilling basin

SHADEHILL DAM
MODEL VIEWS
1:12.52 Scale model

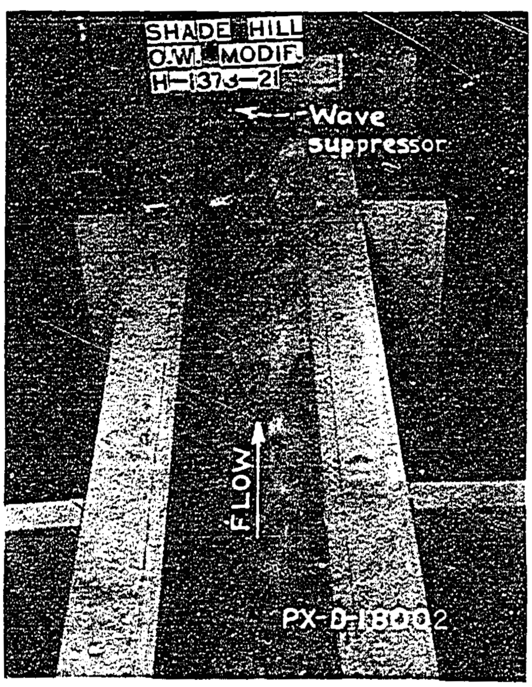
FIGURE-9
REPORT HYD-453



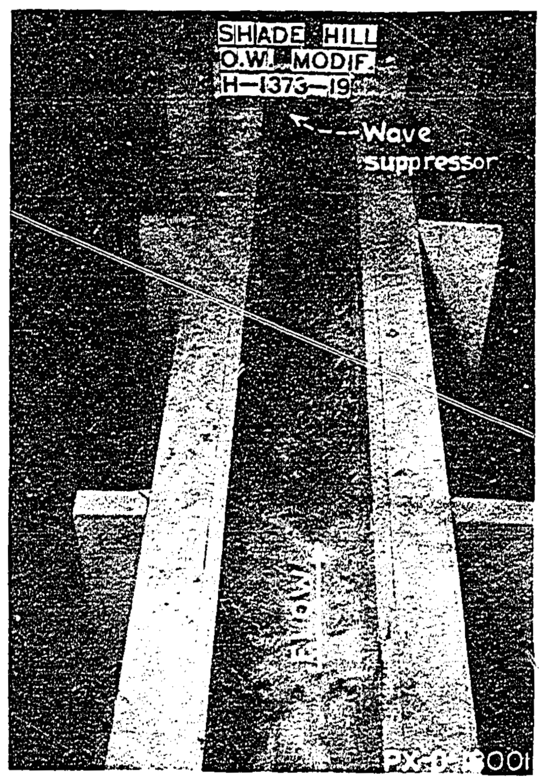


A. Flow conditioning downstream from wave suppressor F=3.5

B. Flow conditions downstream from wave suppressor F=2.5

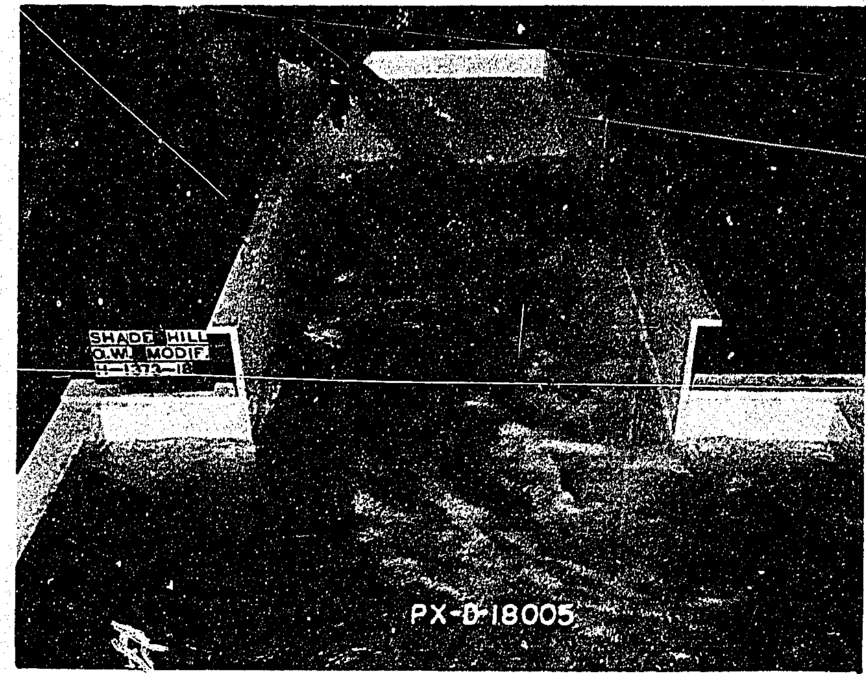


C. Flow conditions in basin F=3.5

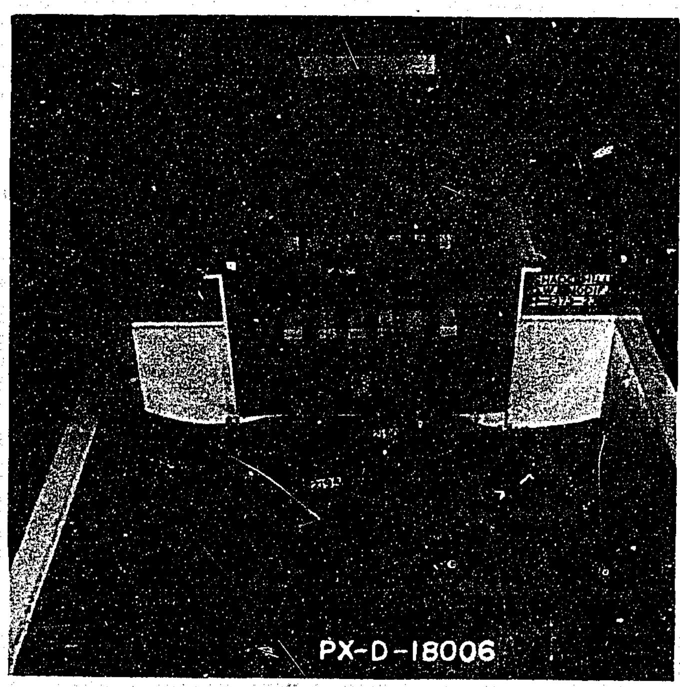


D. Flow conditions in basin F=2.5

SHADEHILL DAM
PRELIMINARY OUTLET WORKS STILLING BASIN - 600 CFS
1:12.52 Scale model

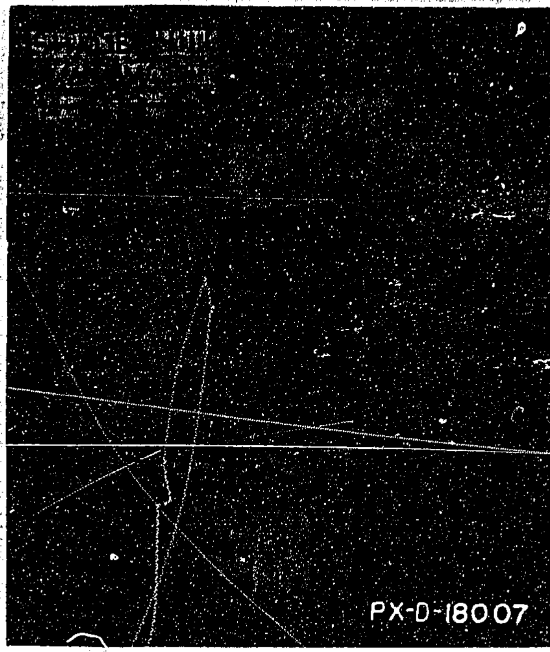


A. 600 cfs entering service spill-way stilling basin T. W. Elev. 2197

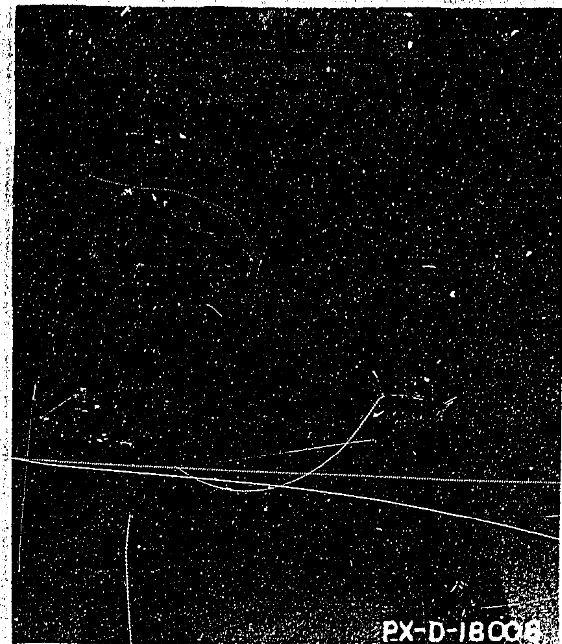


B. Erosion after one hour model test run at 600 cfs. See Figure 8 for channel bed elevations before test run

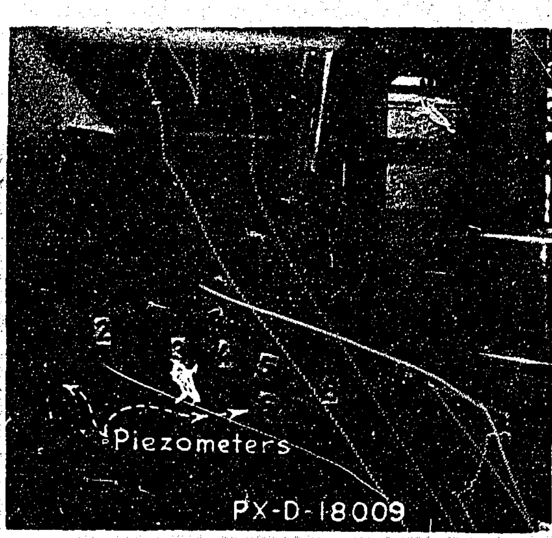
SHADEHILL DAM
PRELIMINARY 6-FOOT DIAMETER PIPE EXIT - 600 CFS
1:12.52 Scale model



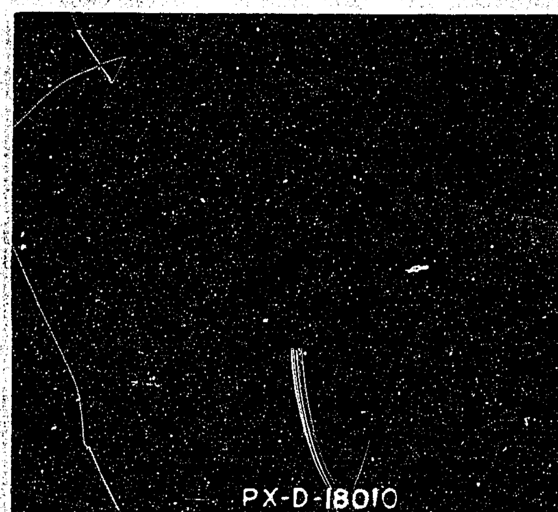
A. Chute block



B. Baffle piers and connecting slab

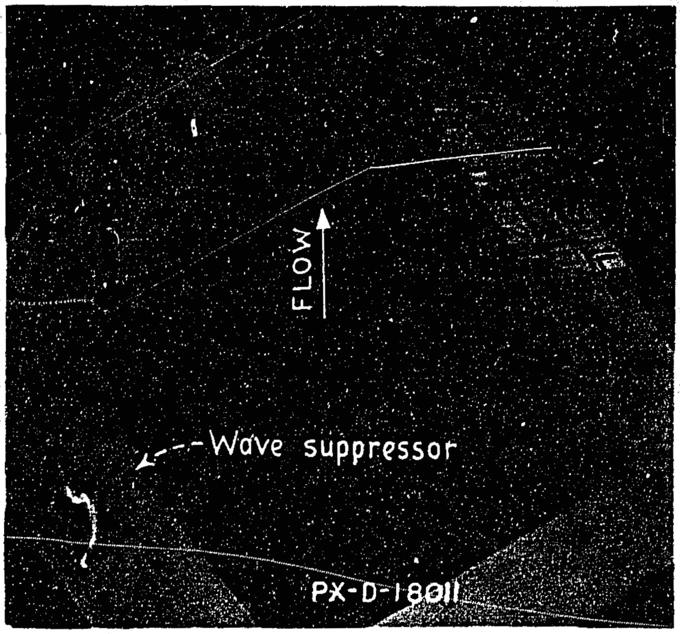


C. Deflector and air vent in crown of transition section

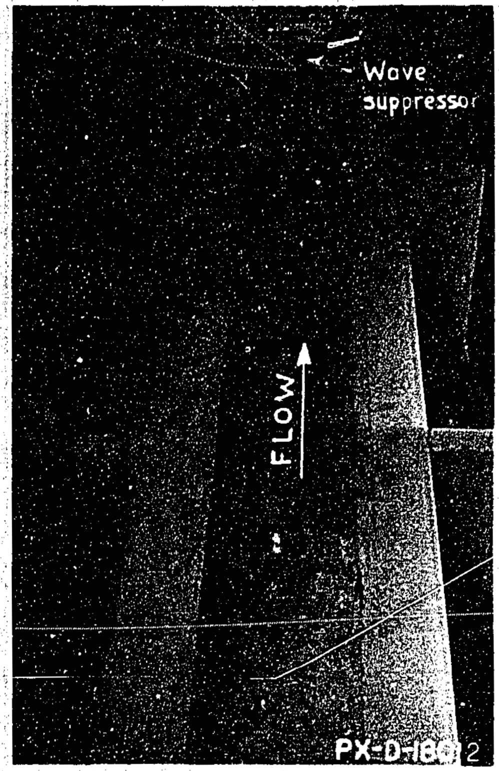


D. Curved trajectory end piece at exit of 6-foot diameter pipe

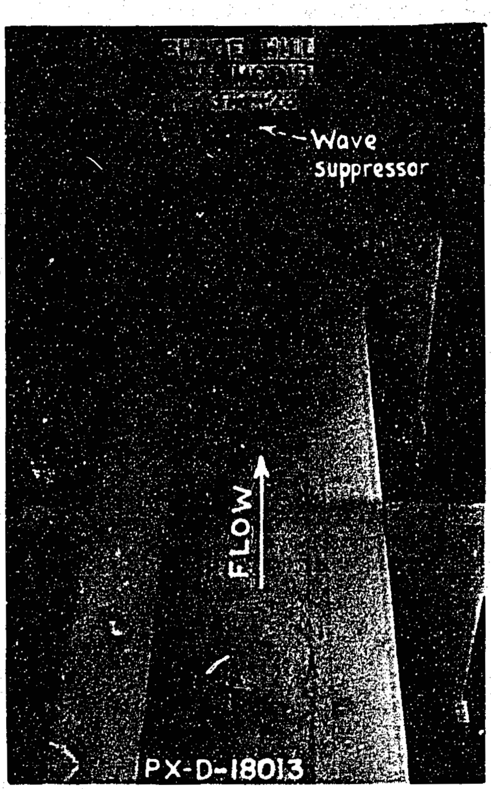
SHADEHILL DAM
RECOMMENDED MODIFICATIONS
1:12.52 Scale model



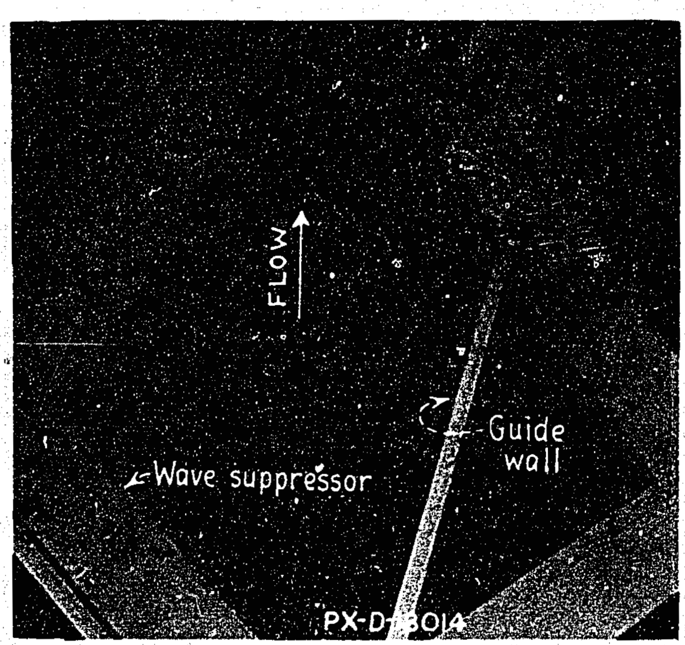
A. Flow conditions downstream from wave suppressor F=3.5



B. Flow conditions in basin F=2.5

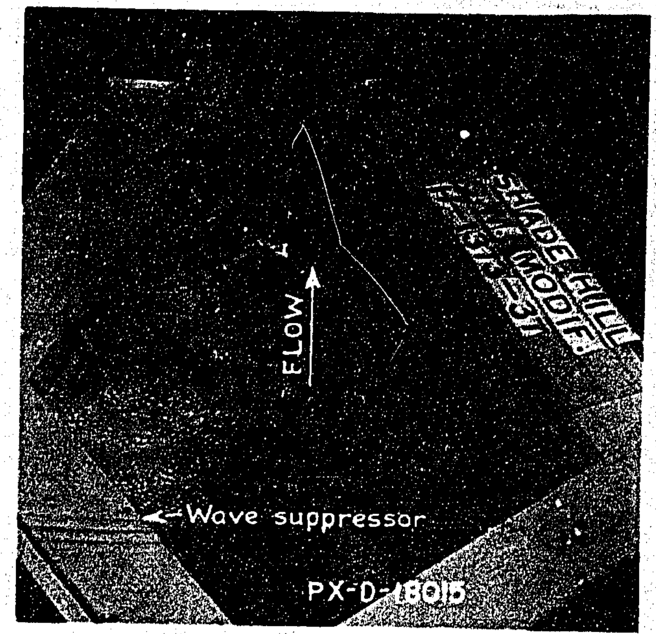


C. Flow conditions in basin F=3.5

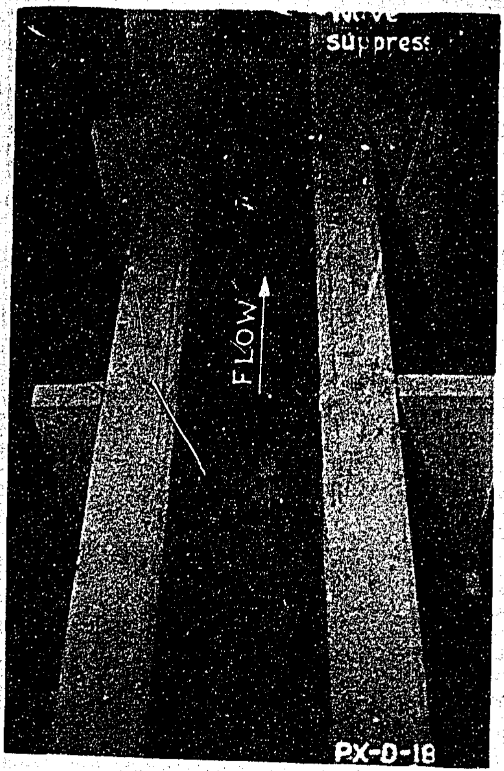


D. Flow conditions downstream from wave suppressor F=3.5 (Guide wall not used in the recommended design)

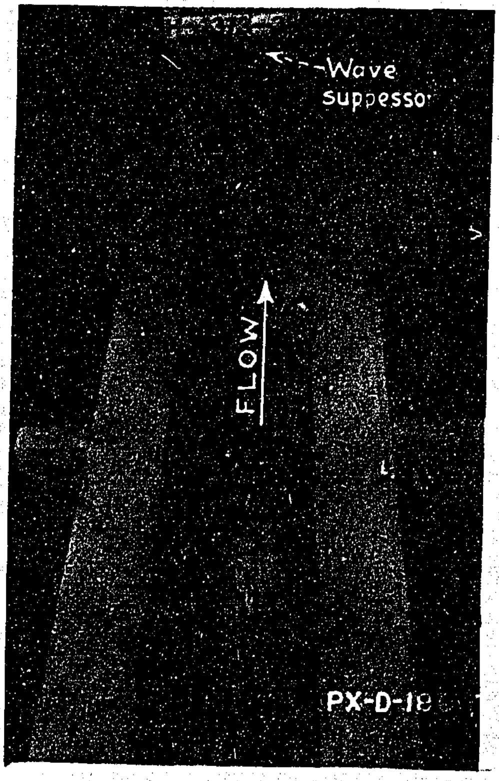
SHADEHILL DAM
RECOMMENDED OUTLET WORKS - 600 CFS
1:12.52 Scale model



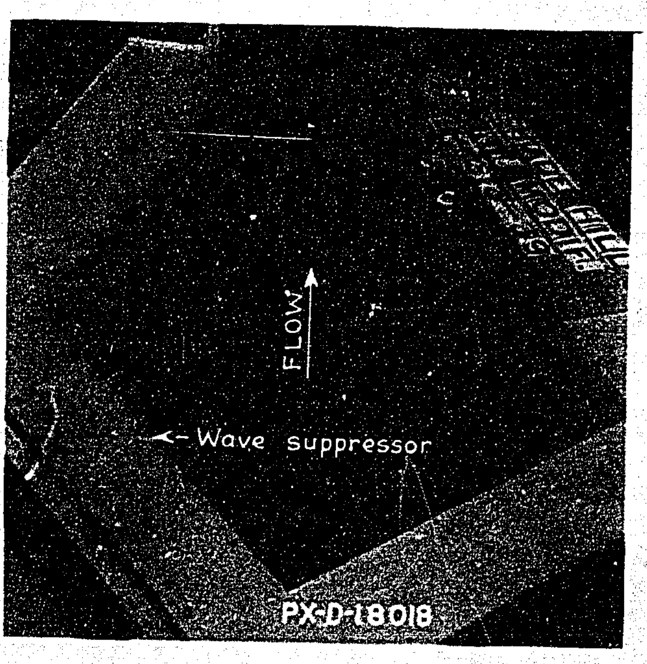
A. Flow conditions downstream from wave suppressor Q=750 cfs, F=3.5



B. Flow conditions in basin F=2.5

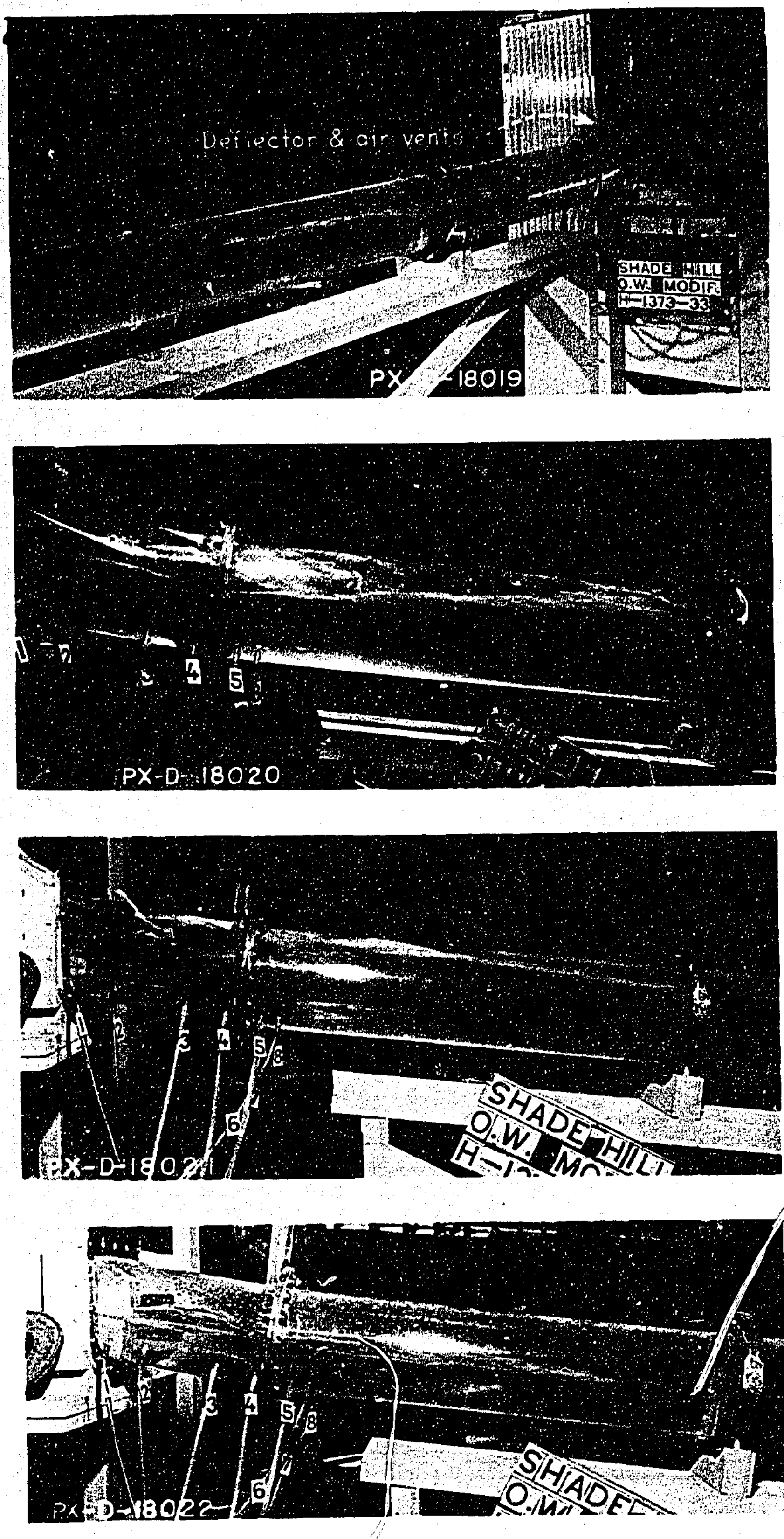


C. Flow conditions in basin F=3.5



D. Flow conditions downstream from wave suppressor Q=300 cfs, F=2.5

SHADEHILL DAM
RECOMMENDED OUTLET WORKS - 750 & 300 CFS
1:12.52 Scale model



A. 600 cfs

B. 600 cfs

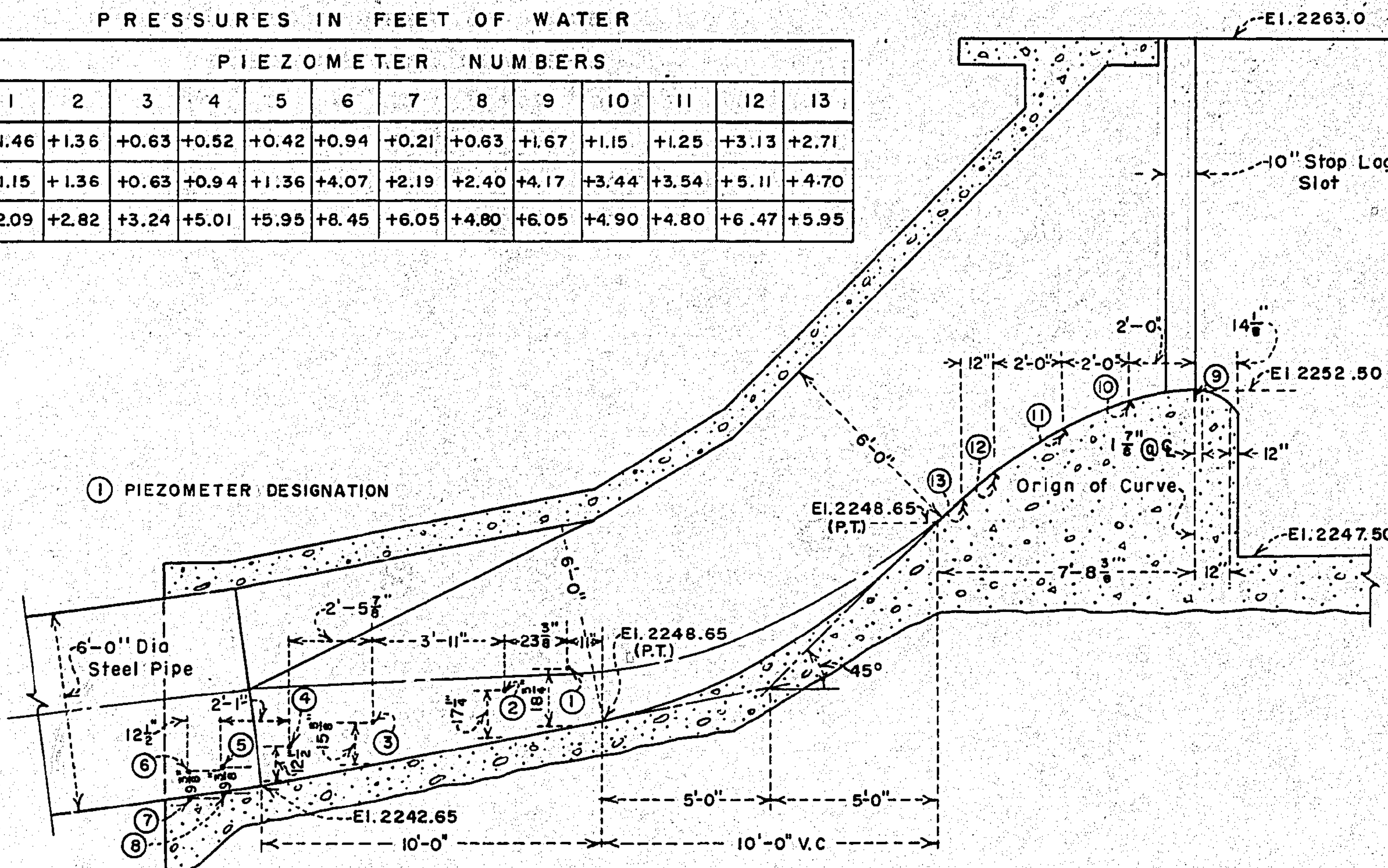
C. 750 cfs

D. 300 cfs

SHADEHILL DAM
TRANSITION FROM CREST TO PIPE WITH RECOMMENDED
DEFLECTOR AND VENT
1:12.52 Scale model

PRESSURES IN FEET OF WATER

DISCHARGE IN C.F.S.	PIEZOMETER NUMBERS												
	1	2	3	4	5	6	7	8	9	10	11	12	13
300	+1.46	+1.36	+0.63	+0.52	+0.42	+0.94	+0.21	+0.63	+1.67	+1.15	+1.25	+3.13	+2.71
600	+1.15	+1.36	+0.63	+0.94	+1.36	+4.07	+2.19	+2.40	+4.17	+3.44	+3.54	+5.11	+4.70
750	+2.09	+2.82	+3.24	+5.01	+5.95	+8.45	+6.05	+4.80	+6.05	+4.90	+4.80	+6.47	+5.95

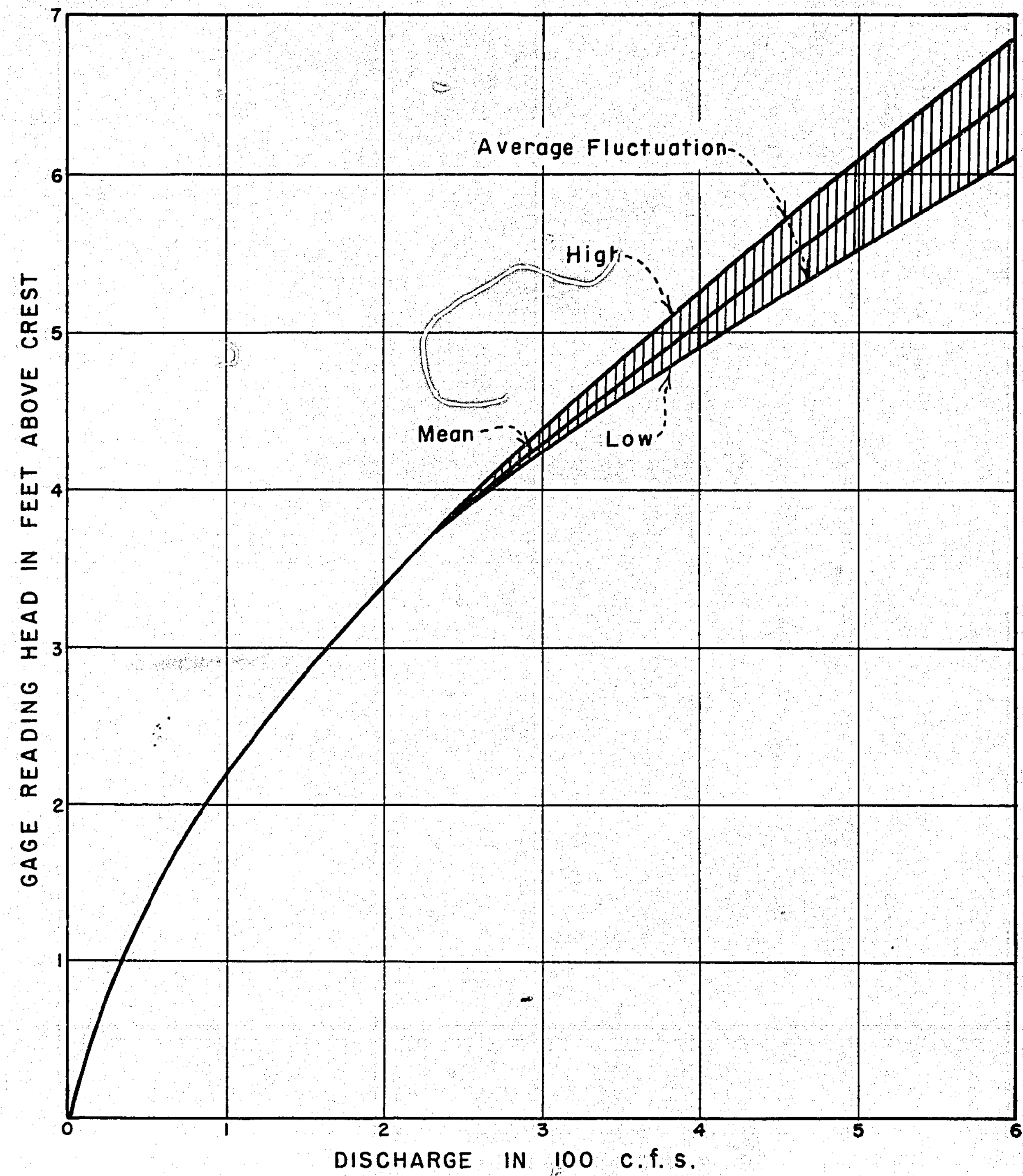


SCALE IN FEET

SHADEHILL DAM OUTLET WORKS
CREST AND TRANSITION PRESSURES
1:12.52 SCALE MODEL

FIGURE 16
REPORT HYD. 453

FIGURE 17
REPORT HYD 453

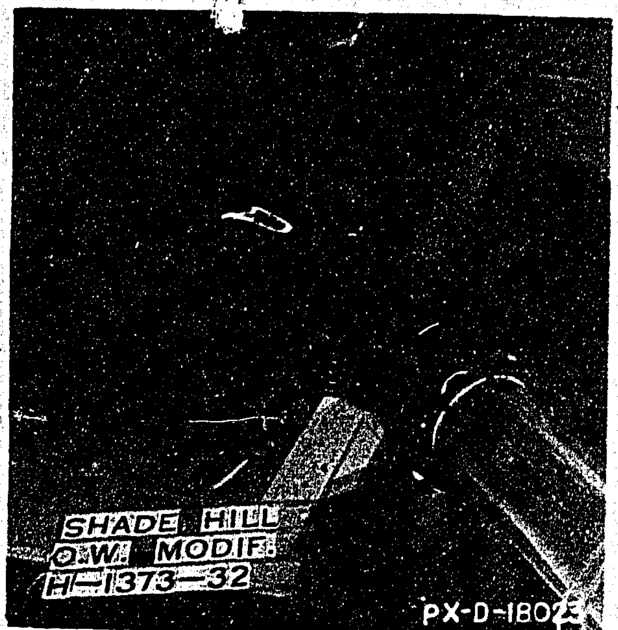


NOTE: Head Measured at Weir Gage Shown on Dwg. 276-D-182, FIGURE 4.

SHADEHILL DAM OUTLET WORKS

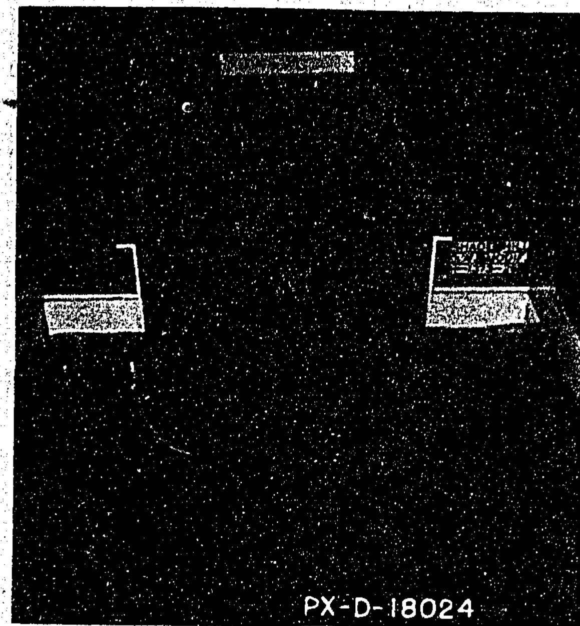
CREST CAPACITY VS. HEAD

1:12.52 SCALE MODEL



A. 600 cfs. T. W. El. 2197

Note spinning action given to water in curved trajectory piece. Exit is not sealed and normal pipe ventilation is preserved.



B. 600 cfs, T. W. El. 2198

Note expanding hollow jet produced by curved trajectory piece.

C. Erosion after one hour model test run at 600 cfs with tailwater at elevation 2197. See Figure 8 for channel bed elevations before test run.

SHADEHILL DAM
RECOMMENDED 6-FOOT DIAMETER PIPE EXIT - 600 CFS
1:12.52 Scale model

Figure 18
Report hyd 453